this period. In the southern part of the lake, however, sediment input is similar to that of the preceding period and in some cases most noticeably Polygon Twenty-One, there is a slight increase in the amount of clastic input.

9.7.3. Zone VII (850-0 Years B.P.)

The most recent period of disturbance with in the Lake Pátzcuaro Basin began approximately 850 years ago. This was marked by a massive influx of clastic sediment in all parts of the lake (Table 9.7). In general, input has been greatest in the Northern Basin with up to 0.52 t m^{-2} at LP20. Much lower values of sediment input are found in the Southern Basin although very large quantity of material accumulated in Polygon Twenty-One with influx at a rate of 2,577 t yr^{-1}. In other parts of the Southern Basin the rate of influx has been considerably lower in the order of 140-448 t yr^{-1}. Over the last 850 years in the order of 24,654081 t of clastic material has been deposited into the lake at an average rate of 29,005 t yr^{-1}. This is equivalent to about 35 t km^{-2} yr^{-1}, and represents an enormous increase in the amount of sediment being transported into the basin, being about seven times greater than the rate of influx during accumulation of zone 6, and about 3 times greater than during accumulation of **Zone V**.

9.7.4 Summary

Although it has not been possible to estimate any values of sediment influx for periods of disturbance prior to 2,500 years B.P., it is evident from these results that there have been considerable differences in the amount of sediment input into Lake Pátzcuaro both temporally and spatially. During the second disturbance phase (Zone V), erosion appears to have been almost entirely isolated to the northern part of the basin. Only at one site, LP11, which is situated close to the southern shore of the lake, is there any real evidence of increased sediment influx in the southern part of the catchment during this period.

A slight increase in the amount of sediment entering the Southern Basin is

Polygon No.	Core No.	Thickness of layer (cm)	Mean Bulk Density	Mean $CaCO_3$ Content %	Mean L.O.I. %	Mean SiO_2 %	% Clastic Sediment	Polygon m^2	t/m^2	Total tonnes	t/yr
1	20	150	0.43	5	11	5	78	511422.0	0.52	2659394	3129
2	19	145	0.40	3	11	5	81	4761077	0.47	2236754	2632
3	18	98	0.29	13	12	5	70	5302155	0.20	1054810	1240
4	17	95	0.29	5	14	5	76	4972778	0.21	1041200	1225
5	16	100	0.30	3	16	5	76	6728463	0.23	1534089	1804
6	14	74	0.36	8	12	5	75	5314241	0.20	933291	1098
7	15	82	0.23	13	12	5	70	4671128	0.13	308242	362
8	13	130	0.23	4	12	5	79	2334812	0.24	658941	775
9	9	56	0.24	5	15	5	75	2789643	0.10	281196	330
10	10	60	0.24	6	13	5	76	5350787	0.11	585590	688
11	8	55	0.26	8	11	5	76	3563847	0.11	387318	454
12	7	65	0.27	8	13	5	74	6062597	0.13	787349	926
13	MC	70	0.25	5	13	5	77	5233226	0.13	7051772	829
14	6	50	0.23	10	16	5	69	4594711	0.79	364590	428
15	5	100	0.25	4	18	5	73	8627296	0.18	1574481	1852
16	4	55	0.29	4	18	5	73	3268616	0.12	380581	448
17	12	65	0.25	14	13	5	68	2072629	0.11	229025	269
18	3	85	0.27	9	16	5	70	786115	0.16	126289	148
19	11	65	0.22	9	16	5	70	1185693	0.10	118687	140
20	1	55	0.27	8	13	5	74	1373773	0.11	150963	178
21	2	70	0.28	8	13	5	74	4211383	0.52	2190222	2572
							Total input for lake =			24,654081t	29005 t/yr

Table 9.7 Variations in clastic input into Lake Pátzcuaro over the last 850 years.

noted between 1,200 and 850 years B.P. (Zone VI), although levels of sediment input remain low. In marked contrast cores from other parts of the lake indicate a considerable decrease in the influx of clastic material; thus a significant decrease in erosion.

All parts of the basin record a dramatic increase in clastic influx and hence erosion over the last 850 years. As with the preceding disturbance phase, influx has been greatest in the northern part of the lake.

When compared to the levels of soil loss from other environments the estimates of erosion presented here are not high. Erosion rates of 35 t/kg^{-2}/yr^{-1} are considered to be normal for Europe (Walling and Webb, 1983 a) and it is not unusual in tropical environments to have erosion rates in excess of 600 t/kg^{-2}/yr^{-1} (Lal, 1977). However, the estimates of erosion rates given here, are based on the accumulation of sediment in the lake and make no allowances for the extremely large quantities of colluvium that have been deposited around the lake. It would not be unreasonable to expect these figures to be considerably higher than those given here. These data indicate that there has been considerable variations in sediment input into the lake, both on a temporal and spatial scale. Moreover, there has been a long history of disturbance within the basin, which has become progressively more severe with successive periods of human activity within the catchment.

CHAPTER 10:- DISCUSSION

10.1 THE HUMAN DISTURBANCE RECORD

10.1.1 Techniques

This study has utilized a number of different research methods and analytical techniques to establish late Holocene environmental change in the Basin of Pátzcuaro, Michoacán, México. The research method was designed to complement and add to the existing palaeoenvironmental data for Lake Pátzcuaro.

The history of environmental degradation within the basin has been based primarily on the lake sediment record. By taking multiple cores it has been possible to correlate stratigraphic layers throughout the lake, based on the magnetic susceptibility and sediment chemistry records. These data have allowed spatial and temporal variations in sediment input into the lake to be determined, as well as highlighting those parts of the basin that have suffered the most severe degradation. Although a number of investigations have used multiple cores (Bloemendal, 1982; Dearing et al, 1981; Davies et al, 1984) this is the first study to use this approach in México.

The results of the sediment chemistry analysis supports and adds to the results obtained from the analysis of the physical properties of the cores. Periods of disturbance within the catchment being associated with increased values of those elements associated with clastic material. By adopting a fractionation digestion technique, recently developed by Engstrom and Wright (1984), it has been possible to establish whether sediment input into the lake has been dominated by weathered or unweathered sediment. Such data allow us to draw some conclusions as to the style of erosion that has occurred within the basin in the past. The sediment chemistry data have been analysed using a multi-variate statistical technique. This has helped reduce the large data set to more compact groups and facilitated interpretation of the data.

Although Street-Perrott et al. (1989) were able to identify two phase of disturbance within the basin, it was not possible in this study to differentiate periods of disturbance from the terrestrial sediments investigated. However, the results do broadly confirm those of the lacustrine investigation. The various historical sources that have been used in this study have enabled some assessment of the extent of degradation since the Conquest.

10.1.2 Summary of the history of environmental degradation in the Basin of Pátzcuaro.

The results of this investigation clearly indicate that the Basin of Pátzcuaro has experienced long term environmental degradation. The earliest event which can be attributed to human activity within the basin began approximately 3,500 years ago and coincided with the introduction of sedentary farming techniques. Both the physical and chemical properties of the lake sediment record suggest that this was not an intense period of disturbance. Unfortunately, the cores collected from the northern part of the basin do not cover this time period and therefore, it is not possible to conclude whether this event affected the entire drainage basin.

A second, much more intense episode of erosion occurred within the basin approximately 2,500-1,200 years B.P. Although it is evident that the entire basin was subject to erosion there was little sediment influx into the southern portion of the lake compared to the north during this period. This difference in sediment influx rate may be a result of the steep slopes and greater sediment source area in the northern part of the lake basin. It would appear, however, that the people who occupied the basin at this time were concentrated in the northern part of the catchment. It is possible to speculate as to why these early settlers preferred to occupy the steeper northern slopes as opposed to the gentler terrain in the southern part of the basin. As discussed in Chapter Three the Postclassic Purépecha preferred to farm the steeper slopes as this protected the crop from frosts during the early part of the growing season. A second possibility is that by locating in the northern part of the basin the population were geographically closer to settlements in the adjoining basin of Zacapu. A further possibility is that the dense network of gullies observed in the northern part of the basin may have been established by the time these people settled in the basin. These could have provided a simple form of irrigation, with the diversion of water from the gullies onto fields located close by. This method of irrigation appears to have been quite widespread in the Basin of México beginning approximately 2,500 years ago (Sanders et al., 1979: Doolittle, 1990). The gentler slopes situated in the southern part of the basin are much less densely gullied and thus limit the area that could have been farmed under irrigation.

The clastic sediment washed into the lake at this time was predominantly unweathered this implies that gully erosion was the predominant mode of transport of clastic sediment to the lake. Had there been widespread deforestation in this period it would appear likely that there would have been a greater influx of weathered material and it is possible that deforestation may have been confined in the early years of settlement to along the gullies.

Although this area was subject to disturbance between 2,500-1,200 years B.P. it is not possible to determine when the population abandoned the basin. It is quite feasible that disturbance within the basin could have continued for a long time after the population left, as has been noted in the Maya lowlands (Leyden, 1987).

The most recent phase of erosion began approximately 850 years B.P. and coincided with the arrival of the Purépecha in the basin. Erosion during this time has been more severe than in previous phases of degradation, resulting in a considerable increase in sediment accumulation rates in the lake as well as the deposition of thick sequences of colluvium around the lake. As with the previous disturbance phase, erosion was more severe in the northern basin, and although there is evidence to suggest that there was net transfer of clay sediments from the southern to the northern basin by lake current it is unlikely that this has been sufficient to account for the difference in accumulation rates observed. In addition, the terrestrial record clearly indicated that there has been a greater accumulation of colluvium in the northern part of the catchment over this period.

The severe degradation experienced in the northern part of the basin was probably a result of intense land use pressure, especially in the immediate Prehispanic period when a high population was settled in the northern part of the catchment. The large settlement at Tzintzuntzan must have resulted in the almost complete deforestation of the slopes and widespread degradation.

Unlike the previous disturbance phase sediment influx in the early part of this most recent erosional event was dominated by weathered clastic material. This suggests that sediment was transported to the lake by overland flow rather than by gullies. An increase in the quantity of unweathered material is noted in all parts of the lake in the latter part of the recent erosional event. This suggests either an increase in gully erosion or that prolonged erosion in the catchment resulted in the removal of the more weathered upper soil layers and the exposure of the underlying unweathered material. Assuming a constant rate of sedimentation the shift to more unweathered sediment dates to approximately 400-500 years B.P. It is possible, then, that this may be related in some way to the change in farming techniques when the Spanish arrived in this area.

Historical sources suggest that the Basin of Pátzcuaro was severely eroded by the time the Spanish arrived in the area. During the colonial period the dramatic decrease in the population of the basin was sufficient to allow the forests to recover and possibl led to a period of reduced disturbance within the basin. Unfortunately there is insufficient evidence to support this hypothesis. The recent destruction of the forest in the basin has probably resulted in increased degradation in the last century.

10.1.3 The human disturbance record from the Basin of Pátzcuaro in the Central Mexican context.

One of the earliest episodes of anthropogenic accelerated erosion in Central México occurred in the Basin of Pátzcuaro. This event is dated to approximately 3,500 years ago. Although it is not possible to assess its full impact, the available evidence indicates that erosion was not intense. A similar short-lived disturbance episode that dates to approximately 3,200 years B.P. has been recorded at La Piscina de Yuriria, located to the north-east of the Basin of Pátzcuaro (Street-Perrott, pers. comm, 1991). This event has been identified by a small peak in *X*, and an increase in the influx of detrital material such as Fe , Al, and K. (Fig. 3.5).

The palaeolimnological record from La Hoya San Nicolas de Parengueo (SNP) situated to the north of Yuriria, displays an increase in *X* and the input of detrital sediment at approximately 3,000 years ago, at a similar time to the first appearance of maize in the pollen record at that site (Fig. 3.6; Steininger, 1988). This evidence indicates that like the Basin of Pátzcuaro, degradation in the SNP catchment is associated with the introduction of sedentary agriculture in the region. Brown (1984), who investigated the pollen record at SNP, concluded that maize cultivation within the crater lake basin was associated with the Preclassic Chupícuaro culture. If this is the case, settlement by the Chupícuaro at SNP, was 500 years earlier than at the main site associated with this cultural group situated near Acambaro (Fig. 3.6).

The record of human disturbance from Lake Pátzcuaro, La Piscina de Yuriria and SNP suggests the presence of small agriculturally-based settlements within these catchments during the early Preclassic period. The time sequence of the onset of disturbance in these basins suggests that there may have been a northwards migration of early settlers in the early Preclassic. The lack of archaeological information, however, means we can only speculate as to the origin of these people and whether they were culturally related. However, it is clear that many of the small lake basins in the central highlands of México were settled for at least a short period during the early Preclassic. These groups probably established small agriculturally-based villages similar to those that are believed to have proliferated throughout Mesoamerica during this time (Flannery, 1976). While the population densities associated with these early groups was probably very low, it is evident that their action was sufficient to cause minor degradation within a number of basins.

The palaeolimnological records from Lake Zacapu, La Piscina de Yuriria and

Lake Pátzcuaro all indicate intense disturbance beginning approximately 2,500 years ago. In addition, Steininger (1988) reported that erosion within the catchment of SNP, which began at approximately 3,000 years B.P., reached its most intense at approximately this time. This episode of disturbance coincides with the presence of the Chupícuaro culture in this region. The main site was situated near Acambaro in north eastern Michoacán, although settlements associated with this cultural group have also been found elsewhere, most noticeably at Querendaro, Cuitzeo, and Zinapecuaro.

Little is known of the Chupícuaro culture, although it has been suggested that they were fairly advanced both culturally and technologically, and had an economy which were based on permanent agricultural settlement. The Chupícuaro are believed to have had an influence over quite a large area; Porter Weaver (1982) reported that ceramics associated with this cultural group are widespread in Central México.

It is apparent that there was a huge increase in the rate of soil erosion in a number of lake basins in Central México during the late Preclassic. The degree of erosion probably reflects the extent of deforestation and the population density within a given area which may have been quite dense in some of these small basins.

A period of stability within the Basin of Pátzcuaro between about 1,200 and 850 years B.P. can be inferred from the lake sediment record. Likewise the palaeolimnological records from La Piscina de Yuriria and Zacapu indicate that there was a reduction in the degree of degradation in these basins at about this time. The record from SNP, however, suggests that disturbance within this catchment began to decline at approximately 1,700 years B.P., suggesting that this small crater lake was abandoned earlier then other sites to the south. The Chupícuaro culture also abandoned its site at Acambaro at approximately 1,700 B.P. Stevens(1964) concluded that conditions during the early Classic period resulted in the northward migration of the Chupícuaro culture, and certainly ceramics associated with this cultural group have been found as far north as La Quemada (Porter Weaver, 1981). It is not possible to determine whether out-migration from the Basins of Zacapu and Pátzcuaro and in the La Piscina de Yuriria occurred at the same time. Erosion of these sites would have continued for some time after the people left these areas, but for how long and with what degree of severity is impossible to determine. It is evident, however, that there was widespread abandonment of many of these small basins during the late Classic-early Postclassic period during which time there appears to have been a reduction in erosion and possible recovery of the environment.

Widespread environmental degradation occurred throughout Central México during the Postclassic and has continued until today. The onset of erosion in the Basin of Pátzcuaro and La Piscina de Yuriria was almost synchronous, beginning approximately 850 years ago. Problems with the dating control in the Zacapu Basin (Metcalfe, 1985) and SNP (Steininger, 1988) make it difficult to pinpoint the exact timing of this event, although in both cases disturbance began in the last 900 to 1,100 years.

The timing of this event coincides with the arrival of the Purépecha in this region. This group which is believed to have migrated into the area from the north, built up a huge empire during the late Postclassic period and established a number of large cities and fortified towns in the area of Michoacán and Guanajuato. A considerable increase in the rate of erosion is recorded in the Basin of Pátzcuaro during this period. Erosion was most severe in the northern part of the basin, probably due to the high population densities associated with Tzintzuntzan. A marked increase in the rate of sediment accumulation and hence erosion rate is also reported for other lake basins in this area (eg. Metcalfe et al., 1989).

There is no evidence to suggest that there has been an increase in the degree of environmental degradation in Central México since the arrival of the Spanish in this region. In the Upper Lerma Basin, for example, disturbance was most severe during the Preclassic to late Postclassic period (Metcalfe et al., 1991; Fig. 10.1) and decreased during the Posthispanic period. This was probably due to the fact that the Spanish did not settle this area to any great extent and the population over this period was less than during the Preclassic and Classic periods. The evidence from this and other studies dispels ideas that erosion was a result of the introduction of European farming techniques into the New World and clearly indicates that Prehispanic cultures using traditional farming techniques caused severe environmental degradation.

10.2 LATE HOLOCENE CLIMATIC CHANGE IN THE BASIN OF PATZCUARO

Evidence from the different lines of investigation used in this study clearly indicate that the level of Lake Pátzcuaro has fluctuated considerably on both the long and short term. The presence of lacustrine deposits as high as 13 m above the present lake and up to 4 km from the lake shore clearly indicate that in the past Lake Pátzcuaro has been considerably more extensive and deeper than at present. Unfortunately, it has not been possible to determine when these deposits were laid down, although it is likely that they date to the late Pleistocene.

Attempting to infer late Holocene climatic change from the lake sediment record does have its limitations. As discussed in Chapter Nine the geochemical data presented in concentration units and thus a change in one variable will influence all other variables. However, if it is assumed that the peaks in Ca and Sr observed in the sediment chemistry record are associated with low lake levels (hence drier and/or warmer conditions), then it is possible to conclude that at least three low stands occurred during the late Holocene period; these date to approximately <3,640, 3,200 to 2,500 and 1,200 to 850 years B.P.

The sediments associated with these episodes are noticeably rich in root remains; this is especially true of those cores collected from the shallower parts of the lake. It is likely that during those periods when the lake-level was low aquatic vegetation flourished. Certainly, at the present time aquatic vegetation flourishes in the shallower southern part of the lake. The presence of a large quantity of tule remains in the sediments at LP3 during the most recent of these episodes of low lake levels indicates that the lake was about 3-4 m lower than at present.

Hutchinson et al. (1956) also concluded that a large peak in $CaCO_3$ observed in the upper part of the two cores that they analysed from Lake Pátzcuaro were indicative of lower lake levels. This conclusion was supported by the diatom assemblage from these deposits which indicated shallow lake conditions (Hutchinson et al., 1956).

Evidence of climatic change over the last 600 years can be inferred from fluctuations in the level of the lake which has been reconstructed from historical sources. Rising lake levels between ca 600 and 470 years B.P. indicate wetter conditions during this time period. The lake remained at this high level until approximately 300 years B.P. when the level began to drop once again. Very dry conditions are inferred from a further drop in the level of the lake between 200 and 150 year B.P. The last 100 years have seen quite considerable fluctuations in the level of the lake, which have been in response to the prevailing climatic conditions of the time. In recent years, however, human factors have had an overriding influence on the level of the lake.

10.2.2 The Lake Pátzcuaro climatic record in the Central Mexican context

Climatic change inferred from this investigation can be compared with those records available for other parts of Central México (see Figure 10.2). The main evidence for climatic change is based on lake-level variations, higher lake levels being associated with wetter and/or cooler periods. The relative lake-level curves for five lake basins situated in the highlands of Central México are shown in Figure 10.2. Bradbury (1971) reported that Lake Texcoco in the Basin of México was low at this time, which is supported by pollen evidence from the Basin of México which indicates a period of marked aridity (Gonzalez Quintero, 1986). Lake Pátzcuaro and la Piscina de Yuriria both indicate that there was an abrupt change to higher lake levels at about 3,800 years B.P., but this short-lived high stand is not recorded in other basins. Between 3,200 and 2,600 years B.P. Lake Pátzcuaro was relatively low. Low lake-levels can also be inferred from the palaeolimnological records of Lake Zacapu, Upper Lerma Basin and Lake Chalco.

With the exception of Lake Chalco, all the lakes shown indicate a shift to high

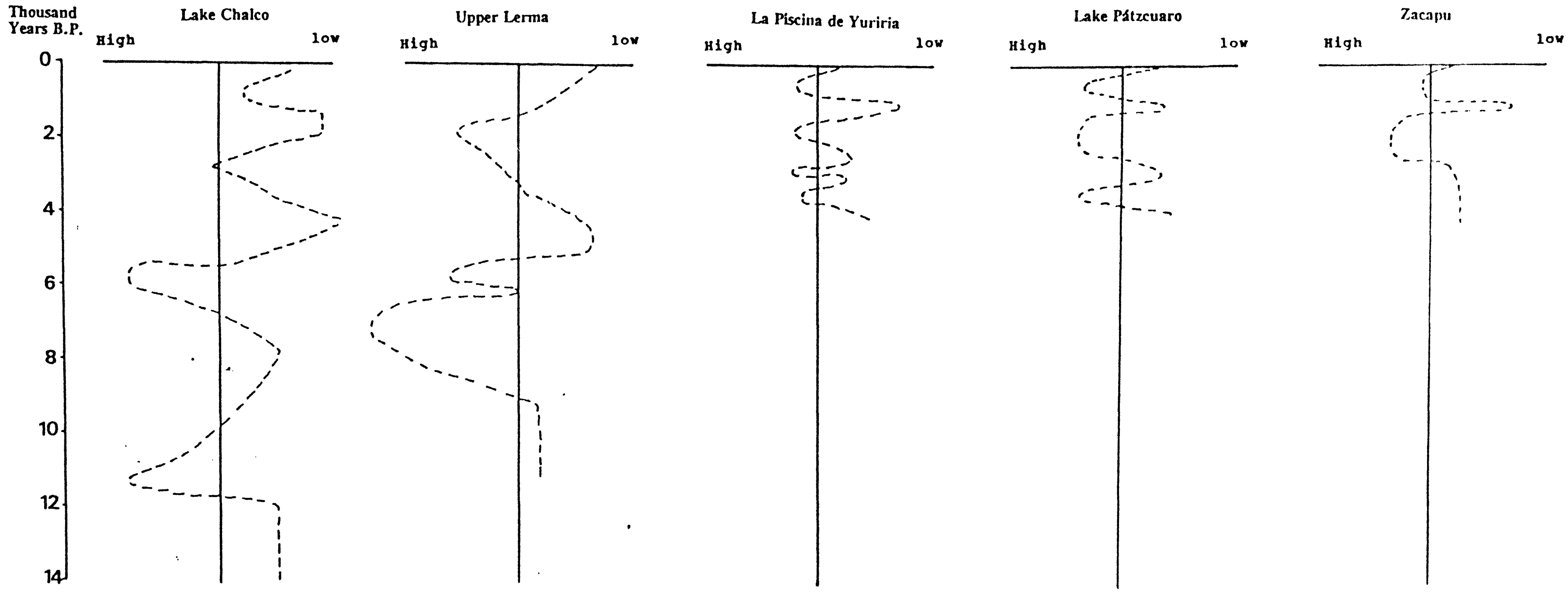

Figure 10.2 Relative lake level curves for selected lakes in Central México.

lake levels between approximately 2,600 and 1,200 years B.P. Other lines of evidence also suggest that Central México experienced relatively wetter climates at this time. A pollen record from coastal Guerrero (Gonzalez Quintero, 1980) also indicates wetter conditions between 3,000 and 2,000 years ago, while Heine (1973,1986) reported that there was a glacial advance at this time. Moreover, it has been suggested by Saunders et al. (1979) that Teotihuacan was established in a period of wetter conditions.

Evidence from the Lake Pátzcuaro record indicates drier conditions between 1,200 and 850 years B.P. and it is believed that the lake could have been as low as 2,032 m a.s.l. at this time. A similar dry phase is also inferred from the lake sediment records from La Piscina de Yuriria and Zacapu. At Zacapu the lowest lake levels occurred at approximately 1,360 years ago while in La Piscina de Yuriria it would appear that the lake all but dried out over this period.

A return to wetter conditions after about 1,000 years B.P. can be inferred from the results of the historical investigation. Lake levels rose from a low level of approximately 2034 m a.s.l. to about 2,039 m a.s.l. by approximately 600 years B.P. and continued to rise until the time of the Conquest. Wetter conditions during this period have also been inferred from other sources. The diatom record from the Zacapu basin, which inferred a low stand at approximately 1,360 years B.P, indicated that the lake had become relatively deep and cool by about 1,000 years B.P. The pollen record from Guerrero also reflects an increase in precipitation towards 700 years B.P. (Gonzalez Quintero, 1980). Metcalfe (1987) concluded that the Aztec period (ca: 650-450 years B.P.) was one of increasing rainfall and that the level of the lake was high at the time of the Conquest, while Heine (1984), has recognised a period of glacial advance at this time which he suggests is coincident with the Little Ice Age glacial advance reported in Europe.

Since the Conquest México appears to have experienced prolonged episodes of drought. Lake Pátzcuaro appears to have maintained a relatively high stand for some time after the Conquest but displays a gradual decline during the late 1600s. Florescano

(1980), using information based mainly on crop yields, concluded that México suffered prolonged periods of drought between the 16th and 19th century. During the mid 18th century Lake Pátzcuaro dropped to extremely low levels which coincided with a period of extreme drought in México. The Yucatán Peninsula was declared a disaster area in 1822-1823 and again in 1834-1835 (Metcalfe, 1987). Changes in the level of Lake Pátzcuaro during this century also closely reflect changes in the climate, and it is evident that the lake responds rapidly to changes in the amount of precipitation and evaporation.

The marked similarity between the lake level curve from Lake Pátzcuaro to those from other lakes in Central México, in particular La Piscina de Yuriria (Fig. 10.2) suggests that the climatic record as inferred from this record is correct. Moreover, it should be noted that the periods of relatively wet and dry conditions are very similar to those outlined by Hutchinson et al. (1956), and despite tha fact that they correlated their sequence with the Basin of México.

10.3 HUMAN AND CLIMATE INTERACTION

The lacustrine record from Lake Pátzcuaro indicates that there is a direct relationship between periods of disturbance and wet phases. This suggests that climate may be one of the most important factors influencing the rise and fall of different Mesoamerican cultures. Dahlin (1983), for example, concluded that a prolonged period of drought caused the collapse of the late Preclassic/early Classic Maya cultures in the Northern Yucatan, and similarly Garcia (1974) concluded that severe drought conditions within the Basin of México may have led to the fall of Teotihuacan.

In the case of the Basin of Pátzcuaro, settlement appears to have been associated with wetter conditions; a similar relationship can also be inferred from the record at La Piscina de Yuriria. It is likely that the link between human occupation and climate is complex and different extremes will have affected cultural groups at different times.

10.4 CONCLUSIONS

The results of this investigation indicate that the Basin of Pátzcuaro has suffered at least three periods of disturbance within the last 3,600 years. These erosional events were a direct result of human activity within the catchment. The earliest period of accelerated erosion began approximately 3,600 years ago and lasted for approximately 200-300 years. A second, more intense episode of disturbance occurred within the catchment between about 2,500 and 1,200 years B.P. The lake sediment chemistry indicates that gulling was the main form of erosion during this period. It is possible that this region may have been inhabited by the Chupicuaro culture at this time. The recent, most intense period of erosion began approximately 850 years ago and coincided with the arrival of the Purepecha in the catchment. The basin has experienced continued degradation since this time, although there is no evidence that suggests there has been an increase in the severity of erosion after the arrival of the Spanish, 470 years ago.

By taking multiple-cores it has been possible to establish spatial and temporal variations in sediment input into the lake. The results of this investigation indicate that during the two most recent episodes of erosion, degradation has been most severe in the northern part of the basin and there has been a much faster rate of sediment accumulation in this part of the lake in comparison to the south

Variations in the level of Lake Pátzcuaro have been inferred from the lacustrine, terrestrial and historical record. These data indicate that Lake Pátzcuaro has experienced considerable fluctuations on both the long and short term. Periods of aridity, associated with low lake levels, date to <3,600 years B.P., about 3,200-2,500 years B.P. and 1,200-850 years B.P. The record of late Holocene climatic change obtained in this study supports the results from a number of recent investigations (eg. Metcalfe <u>et al</u>., 1991; Metcalfe and Hales, in Press) that Central México has experienced significant changes in climate over the last 4,000 years.

The various analytical techniques utilized in this study have provided valuable information on both the human disturbance record and the late Holocene climate record. These data support and add to the results of previous investigations in Central México and provide conclusive evidence that:

i) Periods of accelerated erosion can be associated with Prehispanic culture.

ii) By using multiple cores it is possible to determine spatial and temporal variations in sediment accumulation and establish the source area of those sediments.

iii) That utilizing a variety of research methods and analytical techniques it is possible to separate the human disturbance record from the climate record.

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Worked example of simultaneous R- and Q-mode factor analysis

What follows is a worked example of the above procedure using a hypothetical 6 variable by 16 sample data set. The samples form two distinct groups (perhaps representing samples from two different sedimentary units) and the aim of the analysis is to see if the two groups can be distinguished on the basis of their behaviour over the six variables.

All comments and annotation are in italics. Commands given to MINITAB follow the MTB> prompts. All other text is MINITAB output.

Simultaneous R- and Q-mode factor analysis - Worked example using MINITAB PC 7.1

Print the raw data

```
MTB > print c1-c7
```

ROW	sample	var1	var2	var3	var4	var5	var6
1	A1	3.4	122	0.76	25.3	46.9	3.63986
2	A2	3.7	143	0.72	39.6	61.2	4.15790
3	A3	3.2	165	0.75	22.4	41.9	3.44037
4	A4	3.4	129	0.78	55.9	77.5	4.67896
5	A5	4.0	150	0.79	43.9	65.5	4.30149
6	A6	3.8	137	0.75	22.8	44.4	3.54152
7	A7	3.6	143	0.71	37.1	58.7	4.07209
8	B1	3.9	130	0.69	39.0	60.6	4.13747
9	B2	3.8	143	0.69	25.6	47.2	3.65148
10	B3	3.8	132	0.70	29.8	43.9	3.52152
11	B4	3.7	154	0.71	43.0	64.6	4.27184
12	B5	3.8	163	0.69	47.3	68.9	4.41172
13	B6	3.9	132	0.72	37.3	58.9	4.07902
14	B7	4.0	147	0.73	50.3	68.3	4.39247
15	B8	4.1	142	0.72	22.6	44.2	3.53354
16	B9	3.9	143	0.70	22.9	44.5	3.54551

Put raw data into [X] i.e. [M1]

```
MTB > copy c2-c7 m1
```

Calculate column means and column standard deviations and perform standardization procedure. This was actually done using a short macro. Results reproduced here for completeness. Note:- the formula used for calculation of the column standard deviations was based upon the following MINITAB commands, where c equals the column number

```
MTB > exec 'standard'
```

sqrt(ssq(c) / n(c))

	mean	*standard deviation*
var1	*3.75000*	*0.237171*
var2	*142.187*	*11.5770*
var3	*0.725625*	*0.0308157*
var4	*35.3000*	*10.6890*
var5	*56.0750*	*10.9530*
var6	*3.96105*	*0.387940*

Print the standardized data matrix [W] i.e. [M2]
This has the same dimensions as the original raw data matrix (n rows by m columns).

```
MTB > print m2

MATRIX M2

 -0.368932 -0.435939  0.278875 -0.233885 -0.209418 -0.206982
 -0.052705  0.017546 -0.045634  0.100571  0.116977  0.126858
 -0.579751  0.492625  0.197748 -0.301712 -0.323542 -0.335538
 -0.368932 -0.284778  0.441130  0.481803  0.489021  0.462644
  0.263523  0.168707  0.522257  0.201141  0.215124  0.219392
  0.052705 -0.112022  0.197748 -0.292356 -0.266480 -0.270355
 -0.158114  0.017546 -0.126762  0.042099  0.059915  0.071560
  0.158114 -0.263183 -0.289017  0.086537  0.103282  0.113691
  0.052705  0.017546 -0.289017 -0.226868 -0.202570 -0.199492
  0.052705 -0.219994 -0.207889 -0.128637 -0.277892 -0.283242
 -0.052705  0.255085 -0.126762  0.180091  0.194581  0.200282
  0.052705  0.449436 -0.289017  0.280662  0.292728  0.290427
  0.158114 -0.219994 -0.045634  0.046777  0.064480  0.076026
  0.263523  0.103924  0.035493  0.350828  0.279033  0.278021
  0.368932 -0.004049 -0.045634 -0.297034 -0.271045 -0.275501
  0.158114  0.017546 -0.207889 -0.290017 -0.264197 -0.267786
```

[W] is now transposed to give [W]' and then printed i.e. [M3] Note [W]' has m rows by n columns.

```
MTB > transpose m2 m3

MTB > print m3

 MATRIX M3

-0.368932 -0.052705 -0.579751 -0.368932  0.263523  0.052705
-0.435939  0.017546  0.492625 -0.284778  0.168707 -0.112022
 0.278875 -0.045634  0.197748  0.441130  0.522257  0.197748
-0.233885  0.100571 -0.301712  0.481803  0.201141 -0.292356
-0.209418  0.116977 -0.323542  0.489021  0.215124 -0.266480
-0.206982  0.126858 -0.335538  0.462644  0.219392 -0.270355

-0.158114  0.158114  0.052705  0.052705 -0.052705  0.052705
 0.017546 -0.263183  0.017546 -0.219994  0.255085  0.449436
-0.126762 -0.289017 -0.289017 -0.207889 -0.126762 -0.289017
 0.042099  0.086537 -0.226868 -0.128637  0.180091  0.280662
 0.059915  0.103282 -0.202570 -0.277892  0.194581  0.292728
 0.071560  0.113691 -0.199492 -0.283242  0.200282  0.290427

 0.158114  0.263523  0.368932  0.158114
-0.219994  0.103924 -0.004049  0.017546
-0.045634  0.035493 -0.045634 -0.207889
 0.046777  0.350828 -0.297034 -0.290017
 0.064480  0.279033 -0.271045 -0.264197
 0.076026  0.278021 -0.275501 -0.267786
```

[R] (i.e [M4]) obtained (and then printed) by matrix multiplication of [W]'.[W]

```
MTB > multiply m3 m2 m4

MTB > print m4

 MATRIX M4

  1.00000  -0.03301  -0.33779   0.05375   0.04956   0.06436
 -0.03301   1.00000  -0.12209   0.08121   0.08476   0.08306
 -0.33779  -0.12209   1.00000   0.17248   0.19151   0.17526
  0.05375   0.08121   0.17248   1.00000   0.98355   0.98119
  0.04956   0.08476   0.19151   0.98355   1.00000   0.99927
  0.06436   0.08306   0.17526   0.98119   0.99927   1.00000
```

Eigenvectors and eigenvalues are extracted from [R]. The eigenvectors are stored in [U] (i.e. [M6]). The eigenvalues are stored in an empty column in the MINITAB worksheet (i.e C30). [U] and C30 are then printed.

```
MTB > eigen m4 c30 m6

MTB > print m6

 MATRIX M6

-0.022119 -0.686603  0.364600  0.628536  0.007152  0.006703
-0.060854 -0.211978 -0.926814  0.303907  0.003617 -0.002439
-0.143950  0.691573  0.081834  0.702911  0.010931 -0.010214
-0.567576 -0.043839  0.021420 -0.089021  0.815436 -0.051152
-0.571947 -0.032959  0.018602 -0.070604 -0.362171  0.731636
-0.570807 -0.048584  0.024104 -0.074759 -0.451345 -0.679659

MTB > prin c30

  ROW       C30
    1   3.03245
    2   1.34041
    3   1.01803
    4   0.58545
    5   0.02321
    6   0.00046
```

Given these eigenvalues, the percentage of the original variation explained by the first three factors is 50.5, 22.3 and 16.7 respectively (i.e. 89.5% of the total variation).

[^] is now formed (i.e. [M7]) and printed.

```
MTB > sqrt c30 c31

MTB > diagonal c31 m7

MTB > prin m7
 MATRIX M7

 1.7413932  0.0000000  0.0000000  0.0000000  0.0000000
 0.0000000  1.1577595  0.0000000  0.0000000  0.0000000
 0.0000000  0.0000000  1.0089725  0.0000000  0.0000000
 0.0000000  0.0000000  0.0000000  0.7651466  0.0000000
 0.0000000  0.0000000  0.0000000  0.0000000  0.1523564
 0.0000000  0.0000000  0.0000000  0.0000000  0.0000000

 0.0000000
 0.0000000
 0.0000000
 0.0000000
 0.0000000
 0.0213351
```

$[A^R]$ is formed and then printed (i.e [M8]) by multiplication of [U].[^], giving the R-mode (variable) factor loadings.

```
MTB > multiply m6 m7 m8

MTB > print m8

 MATRIX M8

-0.038518 -0.794921  0.367872  0.480923  0.001090  0.000143
-0.105970 -0.245420 -0.935130  0.232533  0.000551 -0.000052
-0.250673  0.800676  0.082569  0.537830  0.001665 -0.000218
-0.988373 -0.050755  0.021612 -0.068114  0.124237 -0.001091
-0.995984 -0.038158  0.018769 -0.054022 -0.055179  0.015610
-0.993999 -0.056249  0.024320 -0.057201 -0.068765 -0.014501
```

$[A^Q]$ is formed and printed (i.e. [M9]) by multiplication of [W].[U], giving the Q-mode (sample) factor loadings.

```
MTB > multiply m2 m6 m9

MTB > prin m9

 MATRIX M9

 0.365215  0.565793  0.278449 -0.117268 -0.022620 -0.004835
-0.189730 -0.013519 -0.031824 -0.086567 -0.018426 -0.005710
 0.502200  0.470582 -0.672335 -0.000897  0.022392 -0.000337
-0.855244  0.559033  0.196091 -0.120362  0.008112  0.012416
-0.453707  0.117914 -0.003943  0.534510 -0.004712 -0.005988
 0.449852  0.159051  0.121486  0.203133 -0.017730  0.002344
-0.078332  0.009880 -0.080542 -0.196478 -0.022121 -0.006762
-0.118962 -0.265370  0.284434 -0.207251 -0.021135 -0.001479
 0.397866 -0.213468 -0.034133 -0.115282 -0.024311  0.002246
 0.435774 -0.104764  0.191345 -0.127612  0.120898 -0.001215
-0.323938 -0.129589 -0.253701 -0.089450 -0.014855 -0.002653
-0.479411 -0.367396 -0.402521 -0.100804 -0.009396  0.004632
-0.090366 -0.101357  0.261841 -0.013954 -0.019687 -0.004826
-0.534672 -0.216503  0.022074  0.150449  0.062184 -0.001604
 0.479525 -0.248671  0.116486  0.264755 -0.017577  0.007084
 0.493928 -0.221619  0.006793  0.023075 -0.021020  0.006683
```

The contents of $[A^R]$ and $[A^Q]$ are copied to some free columns in the worksheet to allow plotting. Data for factor 1 goes into the first column etc. Other columns are sets up as 'labels' (C40 and C50) for the original variables so that they can be distinguished in the scatter plots (i.e variables 1 to 6 and sample sets A and B).

```
MTB > copy m8 c41-c46

MTB > copy m9 c51-c56

MTB > set c40

DATA> 1 2 3 4 5 6

DATA> end

MTB > set c50

DATA> 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2

DATA> end
```

The MINITAB LPLOT command is used to produce scatter plots with labels of both the variables and the samples on factor 1 vs factor 2. The same axis is used in both plots to allow the relationship between the samples and the variables in factor space to be judged more clearly. As can be seen, the two sample sets seem to be split by factor 2 (C42 and C52 for the variables and the sample respectively). As variables 1 and 3 appear to be the most strongly related to factor 2, it would appear that the split seen is most strongly related to variation in these two parameters between the sample sets.

```
MTB > lplot c42 c41 c40;

SUBC> ystart -1 1;

SUBC> xstart -1 1.

C42      -
         -
         -               C
     0.70+
         -
         -
         -
         -
     0.00+  2D
         -
         -                 B
         -
         -
    -0.70+
         -                  A
         -
         -
          ---------+---------+---------+--------C41
                -0.60      0.00      0.60


MTB > lplot c52 c51 c50;

SUBC> ystart -1 1;

SUBC> xstart -1 1.


C52      -
         -
         -
     0.70+
         -    A                   A
         -                          A
         -
         -          A              A
     0.00+               A A
         -             B  B        B
         -         B      B        B2
         -          B
         -
    -0.70+
         -
         -
         -
          ---------+---------+---------+--------C51
                -0.60      0.00      0.60
```

APPENDIX B

PHYSICAL PROPERTIES OF THE CORES

In this section the main physical properties will be described. This will include those factors analysed for all cores as well as grain-size and dual frequency susceptibility analyses carried out at representative sites. The results will be described for each core separately beginning with the most southerly site and progressing northward up the lake.

Lake Pátzcuaro 3 (Fig. 8.2)

This core was collected approximately 750 m in front of the Island of Urenden from 2.5 m of water. 1.50 m of sediment was recovered. The basal unit (126-150 cm) consists of 24 cm of 10YR 4/2 dark greyish brown to 10YR 3/1 very dark grey gyttja, which has a silty texture and crumbled once extruded from the PVC tubing. Despite this the moisture content is high being approximately 80% and the bulk density 0.21 to 0.23. Although vegetation remains were not observed the organic content of this unit is between 30 and 35%. Levels of *X* and are low for this unit.

The basal unit is overlain by 42 cm (84 to 126 cm) of organic rich clayey material. Organic matter was readily observed with a band of reed mat found between 97-99 cm. Layers of ostracode rich sediment were noted in this unit which correspond to high $CaCO_3$ and organic matter and low *X*. Bulk density varies between 0.2 and 0.29 with moisture content falling between 73-82%.

The upper unit comprises of 84 cm (0-84 cm) of structureless clayey 10YR 3/2 very dark greyish brown sediment. This contains approximately 72-80% moisture and has a bulk density of 0.22-0.34. The upper 22 cm is rich in root matter and a number of mollusc shells were recovered. The unit is characterised by low $CaCO_3$ which shows an overall decrease up the core, but is never higher than 8% and a relatively high organic content. This is approximately 13-16%, but increases to over 20% in the upper 20 cm of the unit. A peak in *X* correspond to this unit in general being above 40 kg/-6, although there is a slight decrease in X corresponds to the increase in the upper part of the core .

Lake Pátzcuaro 4 (Fig. 8.2)

A 1.52 m core was collected from 2.88 m of water at LP4 located 1 km west of LP3. Forty two cm (110-152 cm) of crumbly,silty sediment was found at the base of the core. This varied in colour from 2.5YR 5/2 greyish brown in the lower part of the unit to 10YR 2/1 black at the top. Moisture content ranged from 71-76% with bulk densities of 0.23-0.31. This unit has low $CaCO_3$ levels, very low *X* and between 15-20% organic matter. Overlying this unit is a 13 cm (97-110 cm) band of ostracode rich, silty material which exhibits $CaCO_3$ contents in excess of 40%, contains over 25% organic content and shows a slight increase in *X*. The sediments contain between 75-80% moisture and have a bulk density between 0.23 and 0.29.

A 17 cm thick unit of smooth 10YR 3/2 very dark greyish brown clay is observed between 80 and 97 cm. This has lower moisture levels and higher bulk densities that the sediments on both sides of this unit. The former being approximately 74% and the latter 0.27 to 0.29. This layer corresponds to a decrease in $CaCO_3$ a peak in *X* and contains approximately 15 to 18% organic matter. A second ostracode rich gyttja overlies this unit from 55 to 80 cm. As with the first deposits this concurs with low *X*, and peaks in $CaCO_3$ and organic matter. Moisture content is higher being 82 to 84% and bulk density is less being approximately 0.19.

The upper unit is 55 cm (0-55 cm) of clayey structureless 10YR 3/2 mud. This exhibits high *X* and low $CaCO_3$ with approximately 15 to 20% organic content which increases to top of the unit. Bulk density varies between 0.29 and 0.33 with increase in the amount of moisture down column from 71 to 80%. Fragments of mollusc shell were taken out from the upper part of the core.

Lake Pátzcuaro 11 (Fig. 8.2)

LP11 was collected approximately 700 m from the shore of the lake directly north of the town of Huecorio . A 1.89 m core was recovered from this site from approximately 2.76 m of water. The oldest unit comprises of 24 cm (165-189 cm) of crumbly, 10YR 3/2, silty deposits high in organic matter. A thin band of white nodules were noted between 181 and 183 cm. In the upper part of the unit ostracises were noted. These coincide with a small peak in $CaCO_3$, and low *X*. A 34 cm deposit of clayey sediment overlies the basal unit. These sediments display a marked decrease in organic matter, $CaCO_3$ and mean grain-size concomitant with a slight peak in *X*. Moisture contents between 75 and 79% were recorded and the bulk densities varied between 0.19 and 0.26. Between 124 and 142 cm is a layer of ostracode rich sediment. The $CaCO_3$ content of this unit is approximately 50% and the mean grain-size also shows a distinct peak at this level with a slight increase in organic matter observed. In contrast *X* is very low. The top of this unit is capped by 4 cm of fine sand/silty material

The upper unit consists of 120 cm (0-120 cm) of unstructured 10YR 3/2 clay. This sediment displays high *X* levels with a marked decrease in $CaCO_3$ and mean grain-size and contains 12-15% organic matter. At 68 to 78 cm there is a notable decrease in *X*, but apart from a very slight increase in $CaCO_3$ other parameters remain unchanged. A slight change in the stratigraphy was noted at this point with the sediment having a slightly more grainy texture and an increase in the number of ostracises were noted. Furthermore this band of sediment has a slightly higher moisture content and lower bulk densities that the more clayey deposits on either side. An overall decrease in the amount of moisture in this deposit was observed from 72% at the base of the unit to as high as 87% near the top. Furthermore a general decrease in bulk density from 0.34 to 0.14 was recorded. As light decrease in *X* in the upper 10 cm of the core corresponds to a slight increase in $CaCO_3$ and mean grain-size.

Lake Pátzcuaro 1 (Fig. 8.2)

LP1 was collected from 2.1 m of water approximately 1 km to the NE of LP11.

1.55 m of sediment was retrieved from this site. At the base of the core a 30 cm (125-155 cm) unit of gyttja high in moisture and with a low bulk density was found. These sediments are low in $CaCO_3$ and *X* but high in organic matter content. They range in colour from 5YR 2.5/1 black in the lower part of the unit to 2.5YR 3/2 very dark greyish brown further up the column.

An abrupt change in the stratigrapy is noted at 125 cm with the appearance of distinct ostracode rich sediments. The amount of ostracises noted varied up the unit being most abundant in the lowest 24 cm (101-125 cm) of sediment and corresponding to very high $CaCO_3$, organic matter and moisture content and low bulk density and *X* levels. At 100-101 cm is a band of silty black sediment which concurs with a sharp decrease in $CaCO_3$ and organic matter and a small peak in *X*. This unit is probably volcanic in origin. Above this layer bands of ostracode rich sediment are interbedded with more clayey deposits. The former exhibit higher levels of $CaCO_3$ and organic matter content and low *X*. Where ostracises are absent *X* is high and $CaCO_3$ and organic matter generally low.

The upper unit consists of 55 cm (0-55 cm) of 10YR 3/2 clay. It coincides with a unequivocal peak in *X* which remains high throughout the unit, and relatively low but stable amounts of $CaCO_3$ and organic matter. Moisture content is notably less than the more silty deposits underlying this sediment and has a slightly higher bulk density.

Lake Pátzcuaro 12 (Fig. 8.2)

Approximately 2 km west of LP1 a 1.42 cm core was taken from 4.05 m of water. Three units were recognised in LP12 consisting of 44 cm (98-142 cm) of dark, silty gyttja high in organic matter and relatively low in $CaCO_3$ and *X*. Between 98 and 110 cm there is a sharp peak in *X* and a reduction in both the $CaCO_3$ and organic matter content of the sediment.

The middle unit consists of 29 cm of ostracode rich, 5YR 4/2 dark reddish grey material. This has a relatively 'open' structure and a silty texture. Large amounts of root material is present. It is characterised by high $CaCO_3$ content which comprises of upto 50% of the deposit.

Capping this layer is 66 cm (0-66 cm) of clay. The transition from the middle to upper unit is very abrupt and there are equally abrupt changes in *X*, which displays a large peak and $CaCO_3$ and organic matter which decrease notably at the boundary of the two units and remain constant throughout the profile.

Lake Pátzcuaro 2 (Fig. 8.2)

LP2 was collected from 3 m of water approximately 700 m south of the town of Ihuatzio. 1.55 m of sediment was retrieved at this site. As with LP12 three units were clearly distinguished at this location. The oldest consists of 60 cm (95-155 cm) of silty, organic rich material. When sectioned this appeared to have a crumbly texture despite the moisture content being in the order of 72 to 85%. The sediment ranges from black at the base of the section to 5YR 4/2 dark reddish grey. These deposits have relatively low $CaCO_3$ content although a sharp peak in $CaCO_3$ approximately 110 cm concomitant with an increase in organic matter content. At 95 cm there is a marked change to sediments rich in ostracises and plant root remains. This unit which is 24 cm thick shows a decrease in ostracises and an increase in root material up profile.

The upper unit comprises of 71 cm (0-71 cm) of smooth, structureless, 10YR 3/2 clay. This unit displays high *X* and low amounts of $CaCO_3$ and organic matter. In the top 10 cm of the core there is a notable increase in the amount of root material noted which is parallelled by a small increase in organic matter and a slight decrease in *X*. It is notable that the moisture content of these clayey sediments is lower than the underlying silty and more organic deposits. While the bulk density of the former tends to be higher.

Lake Pátzcuaro 5 (Fig. 8.3)

LP5 was collected from the central part of the lake approximately 3 km to the east of Erongaricuaro. The lake is very shallow in this region being approximately 2.53

mm deep. A 1.69 m core was taken from this site. The lowest 8 cm (161-169 cm) of this consisted of crumbly black clayey material rich in root remains which is overlain by 13 cm (148-161 cm) of silty 5YR 3/2 dark reddish brown material. These sediments contain little $CaCO_3$, a mean grain-size of 15 um, increasing organic matter content up core with a concomitant decrease in *X*. Their bulk density is between 0.32 and 0.37 and they contain approximately 70% moisture. A 16 cm thick unit of ostracode rich sediment is found between 132 and 148 cm. This unit has a distinct silty texture and root material was distinguish. Peaks in $CaCO_3$, organic matter, and an increase in mean grain-size were seen, and a decrease in *X* is also observed.

An abrupt increase in *X* occurs at approximately 133 cm with a corresponding decrease in $CaCO_3$, organic matter and mean grain-size. These changes are parallelled by an equally abrupt change to a smooth 10YR 3/2 clay deposit. No structures, root material or ostracises were noted in this layer. Ostracises reappear in the sequence at 115 cm in a 15 cm unit (115 to 100 cm) of silty 5YR 2.5/2 dark reddish brown material. Slight increase in $CaCO_3$ and mean grain-size and a decrease in *X* are noted at this point.

The upper 100 cm of the core is made up of smooth, structureless clay. This ranges in colour from 10YR 3/2 to 2.5YR 3/2 dark greyish brown. Root material is noted throughout the unit although it is particularly abundant in the upper 30 cm of the core. $CaCO_3$ content is low $< 5\%$ and the sediments contain approximately 15% organic matter which increases to 20% in the upper 30 cm of the core. There is a general increase in the moisture content of this core up profile with a gradual decrease in bulk density found.

Lake Pátzcuaro 6 (Fig. 8.3)

Collected 2 km NE of LP5 approximately 1 km from the lake shore LP6 exhibits the most complex sedimentary sequence of all the cores collected. A 1.56 m core was taken at this site where the water depth was 3.7 m. The basal unit consists of 20 cm

(136-156 cm) of silty gyttja which is low in $CaCO_3$ and X and contains approximately 15% organic matter. At 150-151 cm there is a thin layer of black silty material corresponding to a sharp peak in X and a drop in percent organic matter. This is probably a thin ash layer interbedded in this deposit. What appears to be a second ash layer is found between 118 and 132 cm. This unit is made up of a fine sandy material that corresponds to a peak in X and a decrease in organic matter. $CaCO_3$ increases slightly throughout this unit from 10% at the base to 20% at the top. The moisture content of this ash layer is very low being 38% while the bulk density is 0.98 considerably higher than other bulk densities measured.

An abrupt change in sediment type is seen above the ash with a 20 cm deposit of gyttja low in X, high in organic matter and increasing $CaCO_3$ content up profile. The overlying clay layer exhibiting the opposite with a large peak in X and a corresponding decrease in organic matter and $CaCO_3$. Between 50 and 65 cm there is a return of ostracode rich sediments interbedded with clay material. After an initial sharp drop in X at the base of this unit a second sharp peak in X is seen with a slight decrease in $CaCO_3$ also occurring. At the top of this unit (50-60 cm) there is a marked decrease in X, a sharp increase in organic matter and a slight increase in C. Bulk density is low being 0.14 to 0.17 and moisture contents vary between 83 to 87%.

The upper 50 cm of this core comprises of smooth 2.5YR 3/2 dark brown grey clay. There is an abrupt increase in X at the base of this unit with a further increase at approximately 20 cm. $CaCO_3$ and organic matter contents stay decrease gradually up the profile until about 20 cm when a marked decrease in both is noted. The amount of moisture in these sediment is slightly less than the underlying unit being about 76 to 80% while bulk densities are slightly higher being 0.20 to 0.26.

Lake Pátzcuaro 7 (Fig. 8.3)

A 2.00 m core was collected from 5.2 m of water 3 km east of LP6. Three units were identified the oldest consisting of 122 cm (78 to 200 cm) of unstructured 10YR 3/2 clay. $CaCO_3$ content at the base of the core is approximately 10% but this falls to 2 to 3% by 185 cm and remains at more or less the same level throughout the unit. Similarly the amount of organic material and mean grain-size remains relatively unchanged up profile being approximately 11 to 12 % for the former and 5 to 7 ums for the later. The *X* of this unit is high but exhibits a gradual increase up the core. The moisture content of this sediment shows an overall increase up profile from approximately 72 to 80 % while bulk density shows no general trend.

At 78 cm there is a distinct change in sediment type to a more silty deposit with ostracises and root material evident. A slight increase in $CaCO_3$ and organic matter are noted with a sharp decrease in *X*. An increase in mean grain-size to approximately 15 ums is also recorded for this unit. The moisture content of this deposit is high being 85 %.

The top 65 cm of the core consists of similar sediment to the lowest unit being smooth unstructured 10YR 3/2 clay. This section is characterised by low $CaCO_3$ content, approximately 12 to 15 % organic matter and a mean grain-size of around 5 ums. An abrupt increase in *X* occurs at the base of this unit and despite a small decrease in *X* at 44 cm remains high.

Lake Pátzcuaro 8 (Fig. 8.3)

LP8 consists of 1.58 m of sediment collected from 5.57 m of water approximately 1 km north of San Pedro Cucuchuchu. The basal unit comprises of 36 cm (122-158 cm) of silty, gyttja low in $CaCO_3$. Two small peaks in organic matter and *X* are noted between 132 and 140 cm and 122 and 132 cm. A thin band of ostracode rich sediment occurs between 129 and 132 cm corresponding to a large peak in $CaCO_3$ a small increase in organic matter and an abrupt drop in *X*.

Between 72 and 127 cm is a layer of smooth 10YR 3/2 clay. $CaCO_3$ content drops in the lower 20 crn of the sediment to approximately 5 to 6 % and remains at that level. These deposits contain approximately 12 to 15 % organic matter content. At the base of this deposit there is an abrupt increase in *X* which remains high throughout the unit.

An 8 cm band of grainy ostracode rich sediment is seen between 64 and 72 cm. Here there are small peaks in $CaCO_3$ and organic matter and a large drop in *X*. The upper 64 cm of sediment is made up of similar clay to unit 2 and exhibits similar properties with $CaCO_3$ being slightly higher being 8 to 10 % and organic matter being about 10 %. *X* shows a gradual increase to 40 cm and remains constant, but high until the top of the core.

Lake Pátzcuaro 9 (Fig. 8.3)

LP9 was taken approximately 3.5 km north of LP8, 700 m from the lakeshore. A 1.98 m core was retrieved from 6.4 m of water. The basal unit consists of 18 cm of 5YR 3/4 black gyttja rich in organic material, high in moisture and of low bulk density. It has a low $CaCO_3$ content and *X*.

Overlying this is 18 cm (162-180 cm) of 10YR 3/2 clay, with some ostracises present in the upper 5 cm of the unit. A slight increase in *X* and $CaCO_3$ is noted while the amount of organic matter decreases for this unit.

A thin band of clay 3 cm thick caps the clays coinciding with a slight decrease in *X* and organic matter. Above this is an 82 cm (73-155 cm) layer of clay similar to the lower unit. Very high *X* levels correspond with this unit, which is also characterised by low $CaCO_3$ contents and organic matter content of around 15-20%. The moisture content of this sediment shows an overall increase up the profile with a gradual decrease in bulk density.

A slight increase in $CaCO_3$ and organic matter and a large decrease in *X*, is noted between 58 and 70 cm where there is a bed of grainy, relatively silty material. Ostracises and root material are easily recognised in this unit which also has a moisture content of over 80% and low bulk density.

The upper most unit consists of 58 cm of 10YR 3/2 clay similar in character as the two lower clay units, having a high *X*, low $CaCO_3$ content and containing approximately 15 % organic matter.

Lake Pátzcuaro 10 (Fig. 8.3)

A similar stratigraphy to LP9 was recognised at this site. Here a 1.91 m core was taken from 7.55 m of water. The bottom 3 cm of the core is formed of 5YR 2.5/1 black gyttja. At 188 cm there is a high but short-lived peak in *X* with a concomitant decrease in organic matter. This is overlain by a unit of silty gyttja, which exhibits an increase in organic matter and a decrease in *X* up profile. The mean grain-size varies slightly from between 8 ums at 190 cm to 12 ums at 185 cm before dropping again. Although ostracises are noted in the upper part of this unit there is only a slight increase in $CaCO_3$ content of the sediment.

Between 90 and 163 cm deposits are made up of 10YR 3/2 clay. These exhibit very low $CaCO_3$ content, between 12 and 16 % organic matter, have a high *X* and a mean grain-size of 4 to 6 ums. This layer is capped by 18 cm (72-90 cm) of silty material with ostracises and root remains evident. Increases in $CaCO_3$, organic matter and mean grain-size are noted at this point in the core, together with a high moisture content and low bulk density.

The upper unit consists of 62 cm of clayey 10YR 3/2 sediment. A marked peak in *X* corresponds to this layer which has a low $CaCO_3$ content, contains between 15 and 20% organic matter and shows a gradual decrease in mean grain-size up core fr organic matter 12 ums to 4 ums.

Lake Pátzcuaro 15 (Fig. 8.3)

LP15 was retrieved from 9.9 m of water approximately 3 km north of LP10. Three units are recognised. The oldest forms 100 cm of 10YR 3/2 clay which has a low $CaCO_3$ content, contains about 10% organic matter and has a high *X*. The sediment contains approximately 70 % moisture and has a bulk density between 0.34 and 0.44.

Between 92 and 100 cm there is a band of ostracode rich silty sediment with root remains noted. This coincides with a sharp decrease in *X* together with a peak in $CaCO_3$ and organic matter . The upper most unit comprises of 82 cm of clay similar in appearance and character to the lowest deposit, although the former has a slightly higher $CaCO_3$ content. A sharp increase in *X* occurs at the base of the unit which remains high up profile. There is a decrease in organic matter in the lowest 10 cm of the unit from 15 to 10 %, but it remains at about this level in the upper part of the core

Lake Pátzcuaro 13 (Fig. 8.3)

LP13 was collected approximately 1 km to the west of LP15 and 500 m from the lakeshore from 8.75 m of water . The stratigraphy at this site is very similar to that at LP15. Here a 220 cm core was retrieved from 7.5 m of water. Between 145 and 220 cm is a deposit of 2.5YR 3/2 dark greyish brown clay. These sediments contain about 68 % water and has a bulk density between 0.32 and 0.37. A large peak in *X* and organic matter levels of about 11%. In the upper 20 cm of the unit *X* decreases while $CaCO_3$ and organic matter increases.

A 14 cm thick unit of silty material with abundant root material caps the clays. Peaks in $CaCO_3$ and organic matter occur at this level. Although *X* decreases at this point there is a small peak at 140 cm before dropping to a low level at 134 cm. These sediments have a notably higher moisture content than the underlying clays and a much lower bulk density.

From 130 to 0 cm a second deposit of 10YR 3/2 smooth structureless clay is seen. These sediments have a slightly higher moisture and $CaCO_3$ content and lower bulk densities, but similar levels of organic matter and *X*.

Lake Pátzcuaro 14 (Fig. 8.4).

The shortest core collected was LP14 where 142 cm of sediment was retrieved from 7.25 m of water. The stratigraphy at this site was similar to that seen at LP9. The